Assessment of Three Alternative Methods of Nutrient Enhancement (Salmon Carcass Analogs, Nutrient Pellets, and Carcasses) on Biological Communities in Columbia River Tributaries

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Assessment of Three Alternative Methods of Nutrient Enhancement (Salmon Carcass Analogs, Nutrient Pellets, and Carcasses) on Biological Communities in Columbia River tributaries

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Abstract

Marine-derived nitrogen, phosphorous and carbon once delivered to the rivers of the Columbia Basin by spawning salmonids are a critical part of Pacific Northwest ecosystems. Because many of the streams in which salmon spawn and rear are inherently nutrient poor, the delivery of marine-derived nutrients by returning salmon carcasses may be crucial to survival of juvenile salmon and recovery of depleted salmon populations. The recovery of Columbia Basin salmonids is contingent on the existence of fully functioning ecosystems with adequate productivity to support viable populations of salmonids. While a number of enhancement strategies for increasing the ability of streams to support salmonids exist, few studies have evaluated the methodology for enhancing stream productivity. This project takes the critical first steps of a program designed to experimentally evaluate the effects of marine derived nutrients on populations of Snake River spring/summer chinook and steelhead salmon. We are beginning field experiments to evaluate the response if these fish and their foods to alternative methods of fertilization: (1) carcasses additions, (2) carcass analog additions (from Bio-Oregon) and (3) inorganic nutrient addition. This research is novel in that we (1) address basic questions regarding the methodology of nutrient-based techniques to enhance salmon production; (2) use a replicated before-after study design, (3) begin to distinguish between the importance of direct consumption of carcasses by juvenile salmonids from the indirect effects of bottom-up fertilization; and (4) employ a combination of economics and ecology and ask which fertilization technique provides the greatest increase in salmon performance (growth, survival, population growth) per unit dollar. Such analyses should provide a simple, intuitive method for determining which fertilization method is most cost-effective and how fertilization in general compares in cost-effectiveness to other management schemes.

Introduction

Thousands of rivers and streams dissecting the coastal lands surrounding the North Pacific Ocean once supported major populations of Pacific salmon and anadromous trout. Today, however, these once plentiful species are greatly reduced in both abundance and distribution. Fifty-six distinct North American salmonid Evolutionarily Significant Units (ESUs) have been identified, and 26 of these are now listed as threatened or endangered under the U.S. Endangered Species Act. The grim outlook for Pacific salmonids was re-emphasized by the National Marine Fisheries Service (NMFS) with analyses showing 10 of the 11 ESUs investigated in the Columbia River Basin were continuing their decline; 4 of these ESUs are decreasing at a rate of 10% per year (McClure et al. 2003).

Recent research has highlighted that the importance of returning salmon goes far beyond the clear need for reproducing adults (Stockner 2003, Schindler et al. 2003, Gende et al. 2002, Naiman et al. 2002, Bilby et al. 2001). Because more than 95% of the body mass of salmon is accumulated while fish are in the sea, the return of adults represents a transfer of nutrients from marine to freshwater and terrestrial habitats. The nutrients derived from decomposing salmon carcasses (marine-derived nutrients) are now recognized to play an important role in the ecology of the Pacific Northwest (Gresh et al. 2000, Naiman et al. 2002). Indeed, the importance of this subsidy has been suspected for some time. Sockeye salmon were estimated to transport 2 million kg of organic material and 5000kg of phosphorus to the Karluk River System in Alaska (Juday et al. 1932). Similarly, sockeye salmon carcasses were suggested to provide up to 40% of the annual phosphorus budget to lakes and rivers throughout Alaska (Donaldson 1967, Mathisen 1972, Mathisen et al.1988, Kline et al. 1994) and Russia (Krokhin 1975).

Many of the systems in which salmon spawn and rear are inherently nutrient poor. Consequently, the delivery of marine-derived nutrients by returning salmon carcasses appears to be crucial to the growth and survival of juvenile salmon (Larkin and Slaney 1997, Bilby et al. 1996, 1998, Wipfli et al. 1998). Juvenile salmon consume both salmon eggs and the bodies of adults after they have spawned. Young salmon are also likely indirect beneficiaries of increased primary production and insect abundance associated with salmon carcasses (Kline 1990,Wipfli et al. 1998). As a result, the drastic decline in salmon abundance throughout the Pacific Northwest, in general, and the Columbia River Basin, in particular, must be viewed as not only an economic and aesthetic loss, but also an ecological loss (Gresh et al. 2000, Naiman et al. 2002). The lack of spawning adults has likely lead to a substantial nutrient deficit that has contributed to the downward spiral of salmon abundance in the Columbia Basin (Gresh et al. 2000). The recovery of Columbia Basin salmonids is contingent on the existence of fully functioning ecosystems with adequate productivity to support viable populations of salmonids. While a number of enhancement strategies for increasing the ability of streams to support salmonids exist, few studies have rigorously evaluated the methodology for enhancing stream productivity. Our research is designed to experimentally evaluate the effects of marine derived nutrients on populations of Snake River spring/summer chinook and steelhead salmon.

Background on Nutrient Enhancement Strategies

For the past three summers, we have monitored baseline conditions of stream habitat, nutrient chemistry, and various aspects of algal, insect, fish, and bird biomass, abundance and diversity.

This summer we are planning an ecosystem-wide experiment to evaluate the response of salmonids (spring/summer chinook salmon and steelhead) to alternative methods of fertilization. We are evaluating three methods of enhancement: 1) carcass additions, 2) carcass analog additions and 3) inorganic nutrient addition. These forms of enhancement involve addition of organic or inorganic nutrients and may differentially affect juvenile salmonid growth and survival.

The first approach, nutrient enhancement via carcasses, is becoming an increasingly popular management strategy. In August 2000, Washington Department of Fish and Wildlife announced it would be distributing hatchery carcasses for stream nutrient enhancement in at least a dozen streams (WDFW Fact sheet, http://www.wa.gov/wdfw/factshts/howsurplus.htm). Similar programs are in operation in the state of Oregon (http://www.dfw.state.or.us/ODFWhtml/InfoCntrFish/whathappens.pdf) and coastal streams in British Columbia (http://www.bccf.com/steelhead/pdf/Carcass%202002%20Final.pdf). Although carcass enhancement is being adopted as a management strategy, more and more, major issues remain. First, there is a paucity of scientific information to guide managers in basic methods and protocols. Fundamental questions such as how many carcasses are needed, where and at what time should carcasses be deposited, and in which streams might carcass enhancement be most effective remain unaddressed. Second, the increasing use of carcass enhancement in streams has not been coupled with appropriate monitoring and evaluation programs. Subsequently, the opportunity to broadly evaluate the extent to which salmonids benefit from such actions has been lost. If appropriately designed and monitored, data from enhancement programs can be used to quantify how much improvement in salmonid population growth rate we might expect. This information is vital to all those in the region trying to design effective and efficient recovery strategies. Third, as a result of a concern for spreading pathogens, most salmonid enhancement programs permit the addition of only those carcasses that originate from the same watershed. Finally, whereas carcass additions are feasible in systems relatively accessible by roads, the feasibility of broadly applying carcasses enhancement techniques in less accessible areas is much lower given time and resource demands.

A second approach involves using salmon carcass analogs, a new product being developed by Bio-Oregon. Bio-Oregon has developed assorted fish feed used in the aquaculture industry (http://www.bio-oregon.com/flash/index.htm), and is working to develop a carcass analog that will not immediately dissolve when placed in-stream. The carcass analogs will be derived from fishmeal and processed using a pasteurization technique intended to minimize the likelihood of pathogen transfer to streams. Given their compact size, carcass analogs are more easily distributed than actual carcasses. Uncertainties associated with nutrient enhancement via carcass analogs are whether and to what extent these analogs will be directly consumed by fish and other vertebrates or whether these analogs will function more like inorganic fertilizer briquettes. Furthermore, we are unsure how long analogs will remain in-stream compared to true carcasses. Already, there is considerable interest within the region in this yet undeveloped technology (Dennis Roley, Bio-Oregon, personal communication). It is therefore imperative that these analogs be first used in tightly controlled and monitored experiments.

A third approach to enhancing productivity of salmonids via fertilization involves increasing the system's productivity via bottom-up processes using the addition of inorganic nutrients. The addition of inorganic nutrients increases primary producer biomass, subsequently increasing the biomass of higher order producers (invertebrates, fish, riparian vegetation and other wildlife). The BC Ministry of Environment has been conducting a long-term fertilization experiment on the Keogh River in British Columbia using slow release nutrient briquettes that release inorganic nutrients. During this period, they have observed increases in growth and survival rates and numbers of salmonid and non-target fish species (McCubbing and Ward 1997). Recent results indicate that increases in growth rate were concomitant with a shift in life-history strategy in which outmigration of juvenile steelhead occurred one year earlier. As with the carcass enhancement technique, experiments in stream fertilization must address a number of issues. The first issue involves identifying the appropriate levels at which to fertilize and the timeframe over which a response may occur. Short-term, local responses to fertilization are well documented (Johnson et al. 1990, Wipfli et al. 1999, Kiffney and Richardson 2001), but the time needed to build overall system productivity is much longer. Furthermore, a long-term commitment to fertilization may be needed to instigate a positive feedback cycle in which added nutrients stimulate production, salmon growth and survival, and ultimately result in increasing numbers of adult returns bringing more nutrients to the system.

Our research program involves a comparative, experimental approach that has the following elements. First, we address basic scientific questions regarding the methodology of enhancement techniques in an effort to identify the best strategy to fertilize streams in order to increase salmon production. We will compare a novel enhancement technique still under development (carcass analogs) to two enhancement strategies that need to be quantitatively evaluated in an experimental setting (carcasses and inorganic fertilizers). Second, we can begin to distinguish between the relative importance of direct consumption of carcasses by juvenile salmonids and the indirect effects of bottom-up fertilization. Third, these experiments are the first step in evaluating short and long-term effects of differing methods of enrichment. The results from this research will be of great use to management, as this approach evaluates enrichments methods that differ in cost and effort needed to implement. Furthermore, we are testing these approaches at multiple scales, which allow us to identify mechanisms as well as generate results that have direct relevance to management. The ability to link anticipated benefits for salmonids and specific management actions is a vital need throughout the Columbia River Basin. This need to know 'how much bang for the buck' will only amplify as recovery plans are developed and actions prioritized.

Research Sites and Timeline

Our study streams are located in three drainages of the Salmon River Basin, Idaho (Table 1, Figure 1). Rocks of the Atlanta lobe (70-80 million year old Idaho batholith) dominate the geology of this region. This large form occupies the most of the land area of central Idaho, and is responsible for the dominant character and form of the regional landscape. Glaciers covered much of the region as recently as 10,000 years ago; glacial processes have contributed immensely to the form and function of the streams in this basin. Our research sites include 17 streams located within National Forests (Payette, Salmon, Challis and Boise National Forests) and/or Wilderness and Recreation areas (Sawtooth National Recreation Area). Our study reaches range from moderately confined to unconfined in moderately wooded and meadow landscapes.

Our research plan combines baseline monitoring of treatment and control reaches within each study stream, stream channel experiments, and a large-scale ecosystem experiment in which carcasses, inorganic nutrients and analogs are added to streams (Table 4 and 5). These research streams coincide with those studied as part of the ongoing wild-fish monitoring study (Steve Achord, BPA project #19102800) which has measured the survival and size of PIT tagged wild chinook for the last decade from streams we will use as treatments and controls. In addition, this long-term database allows us to employ statistical techniques for determining the efficacy of each of our experimental treatments. We will thus be able to estimate changes in juvenile survival, size and condition as a function of experimental treatment.

Permits

The following is information on permits requested and received for work in 2003. Additional permits will are required in 2004 to cover the upcoming nutrient enhancement experiment.

Permits 2003

USFS National Forest Special Use Permits
- Boise SUP and Biological Assessment of Invertebrate Sampling and Stream Enclosure Experiments (ID#BOI003602, issued 6/5/2003)
- Payette (ID#MCC036, issued 6/17/2003)
- Salmon-Challis (ID#MFK23, issued 6/13/2003)
- Sawtooth National Recreation Area (issued 4/21/2003)

ESA Permit Section 10 (Salmon and Steelhead: #1403, issued 6/30/03)

ESA Permit Section 7 (Bull Trout; permit # 1-7-00-F-336, Study 2)

2003 Baseline Monitoring: Progress and Methods

2003 field sampling began in June in the Salmon River basin. Variables monitored included nutrient chemistry, primary production, invertebrate benthic community and drift, physical habitat, leaf litter decomposition, fish assemblage, bird surveys, and isotope composition of fish, invertebrates, and periphyton. Specific response variables are presented in Table 6. Each stream was sampled three to four times between June and September 2003. Three to five sampling sites were chosen for each of two 1-km reaches (separated by a 0.5km buffer reach) in each stream. In addition, nutrient limitation experiments were conducted in nine streams, along with an in-stream enclosure experiment in one stream studying effects of carcass, analog, and inorganic additions on fish growth, invertebrate and periphyton abundance (Table 2). Finally, a preliminary behavioral study examining the potential effects of non-native brook trout on juvenile chinook was conducted in Summit Creek.

Physical Habitat Characterization: This year, a second reach was characterized for physical habitat, which was measured using standard methods from the EPA Environmental Monitoring and Assessment Protocol (Kaufmann and Robison 1998). This method consists of measuring a suite of physical channel parameters that describe the character of a given reach. A 40-channel width-reach was surveyed in each stream. We characterized stream width, gradient, channel and habitat characteristics (habitat type, sinuosity, substrate composition, water depth), and riparian vegetation. We also conducted Wolman pebble counts at 3-5 riffles in the mapped reach.

Water Chemistry and Quality: Water samples were collected to measure nutrient concentrations (PO_4, $Si(OH)_4$, NO_3, NO_2, NH_3), total nitrogen (TN) and total phosphorus (TP), and dissolved oxygen concentrations. These samples were collected from riffle habitats at 3-5 randomly chosen transects in each stream reach. Nutrient samples were filtered through a 0.45 um cellulose acetate membrane filter. Samples were stored in high-density polyethylene sample bottles and kept frozen until analysis. Dissolved organic carbon samples were also collected, passed through a pre-ashed cellulose acetate membrane filter and stored in glass scintillation vials. All water chemistry samples were analyzed by the WA accredited Marine Chemistry Lab at the School of Oceanography (Univ. of WA). Turbidity samples were collected using 1-liter stream water filtered through ashed filters, dried thoroughly at 70°C, weighed, subsequently ashed at 500°C for 4 hours, and weighed again. Microbial decomposition rates were collected using leaf litter decomposition bags placed in streams and collected over a 4-week time period.

Primary Production: To measure algal biomass, we employed two techniques. We removed periphyton from rocks and also set out clay tiles to measure bioaccumulation over one and two month periods. Periphyton collected from rocks and tiles were diluted with deionized water and filtered onto glass fiber filters. Filters were processed for chlorophyll and ash free dry mass (AFDM) (Steinman and Lamberti 1996). Filters used for AFDM were ashed at 500°C for 4 hours and weighed. Following filtration, filters were dried thoroughly at 70°C, weighed and subsequently ashed at 500°C for 4 hours, and weighed again. Chlorophyll filters were frozen until analysis. Filters were extracted in 90% acetone for 24 hours prior to measurement. Chlorophyll concentrations were measured fluorometrically (Turner Designs Fluorometer, TD-700).

Invertebrate Community Composition: Benthic invertebrates were sampled using a 363μm mesh Hess sampler with sediment disturbed for one minute (Hauer and Resh 1996). Drift invertebrates were also sampled using 363 μm drift nets set out for 15-minute intervals. All samples were elutriated and sieved to remove non-invertebrate materials, and preserved in 95% ethanol. Taxa were enumerated and identified to the lowest taxonomic level (genus when possible).

Fish and Bird Community: Snorkel surveys were performed between July and August 2003. Fish species, abundance, and size were recorded within a 200-m reach within each stream reach. Also, a 500m bird survey (which included the snorkel survey area) along the stream banks was conducted for each stream reach. Species (if possible), abundance, location, and behavior were recorded along these reaches.

Isotope Analysis: Fish, invertebrate, and fish samples for isotope analyses were collected in the field and kept frozen until they were freeze-dried, ground and weighed. Fractionation of the stable isotopes nitrogen-15 ($_{\delta}N_{15}$) and carbon-13 ($_{\delta}C_{13}$) will be analyzed using a Costech elemental combustion system (model 4010) coupled to a Thermo Finnigan Delta Plus mass spectrometer.

Nutrient Limitation Experiment: In nine streams we conducted nutrient limitation experiments with nutrient diffusing substrates. Porous silica discs were placed atop vials filled with agar-infused nitrogen, phosphorus, and nitrogen-phosphorus and control treatments. Racks with these vials were placed in-stream and allowed to accumulate periphyton over two 1-month periods

(August and September). Discs were analyzed for chlorophyll a concentration using the same protocol for primary productivity.

In-stream enclosure experiment: In the South Fork Salmon River we conducted a nutrient addition experiment with in-stream enclosures. Chinook and brook trout were added to enclosures treated with chinook carcass, inorganic, and analog additions. Water chemistry, primary productivity, invertebrate (Hess and drift), and fish samples were collected during the eight-week long experiment.

Brook trout and chinook behavior study: To study the potential effects of non-native brook trout on chinook, in light of planned experiments that may alter food availability for fish, we made in-stream observations of individual chinook and brook trout, quantifying their distribution, habitat use and overlap, and interactions with neighboring fish. We completed 278, 5-min observations while snorkeling in Summit Creek, where density of brook trout is quite high (brook trout: chinook at the end of the summer is ~ 2:3). In addition, we will analyze the stomach contents of fish collected to assess potential diet overlap across streams.

2003 Field Season Results

Baseline data collected in 2002 and 2003 was be used to identify appropriate treatment and control streams for the upcoming nutrient enhancement experiment in 2004. Furthermore, these data are providing pre-treatment data that will be needed to statistically evaluate responses to the manipulation.

Ph*ysical Habitat:* Average wetted widths and stream gradients from second habitat reaches were similar to those measured in 2002. Pebble size was consistently small in several streams (Elk, Sulphur, Summit, and Marsh); pebble sizes were much largest in the Rush and Loon.

Water Chemistry and Periphyton: Ranges of water chemistry and periphyton biomass data are presented in Table 3. Nitrate and phosphate concentrations were often near zero or extremely low (Figure 2). Chlorophyll concentrations between July-September ranged from 0.06 – 55.6 $\mu g/m^2$ (Figure 3, Table 3).

Invertebrates: We are currently seeking funds to contract out invertebrate sorting, identification and enumeration.

Fish and Bird Community: Juvenile chinook were most prominent in snorkel surveys, other fish species observed include rainbow, brook, bull and cutthroat trout, whitefish, dace, sculpin, and suckers. A drop in number of juvenile chinook was observed later in the field season (see Figure 4). Examples of bird species observed include kingfishers (juvenile fish predators), dippers, and sandpipers (aquatic invertebrate predators).

Nutrient Limitation Experiment: Results from this experiment reveal most streams are significantly nitrogen limited and co-limited with nitrogen and phosphorus (Table 5). It is unknown why phosphorus treatments prohibited periphyton growth.

In-stream Enclosure Experiment: Samples are currently being processed for stable isotope analysis. Initial data analysis did not yield significant correlations between additions and primary productivity.

Brook trout and chinook behavior study: We are currently developing statistical models to determine what biological and habitat variables are most important in explaining the number of encounters between fish as well as the outcomes of those encounters. It appears small fish are most often displaced, which suggests chinook may be at a disadvantage in streams with typically larger brook trout. Preliminary analyses of fish stomach contents and feeding behavior indicate chinook and trout consume similar food items, suggesting potential for competition for food if food became limiting.

2004 Research Plan

Our summer 2004 research program includes three elements: baseline monitoring and nutrient addition experiments in Salmon River basin streams, and stream channel experiments in Washington state.

We propose an experimental design of adding analogs, carcasses, or inorganic nutrients to the downstream 1 km reach in each stream between late July and mid-August of 2004. In addition to two control streams, the upstream reach in each stream will be monitored as an additional control. Stream choice for carcass additions was limited by permitting constraints. Streams involved in nutrient addition experiment will be monitored before, during, and after nutrient additions between July and September 2004. Basic baseline data will be collected at non-experimental streams throughout the field season.

The specific aspects of this summer's research plan are described in Tables 5 and 6.

Table 1. Names and locations of research streams monitored during summer 2003.

Drainage	Forest	Stream	Stream Code	Latitude	Longitude
Salmon River	Payette	Chamberlain Creek	CHA	45.21.694	115.13.534
	Payette	West Fork Chamberlain	WFC	45.24.859	115.11.673
	Boise	South Fork Salmon River	SFS	44.34.900	115.40.958
South Fork Salmon River	Payette	Lake Creek	LAK	45.20.342	115.56.945
	Payette	Secesh River	SEC	45.11.737	115.49.206
	Payette	Summit Creek	SUM	45.14.527	115.54.621
Middle Fork Salmon River	Boise	Bear Valley Creek	BVA	44.23.487	115.22.492
	Salmon-Challis	Camas Creek	CAM	44.48.762	114.29.198
	Challis	Loon Creek	LOO	44.36.708	114.47.717
	Boise	Elk Creek	ELK	44.25.317	115.25.612
	Sawtooth	Elk Creek Trib to Valley	ETR	44.17.551	115.01.497
	Payette	Big Creek (Lower)	LBG	45.06.628	114.54.054
	Challis	Cape Horn Creek	CHO	44.21.559	115.12.263
	Challis	Marsh Creek	MAR	44.22.239	115.08.389
	Payette	Rush Creek	RUS	45.05.871	114.51.838
	Salmon-Challis	Sulphur Creek	SUL	44.32.578	115.20.086
	Sawtooth	Valley Creek	VAL	44.14.050	114.59.376

Table 2. Data collected from Salmon River study streams for baseline data and South Fork Salmon River in-stream enclosure experiment in 2003.

Stream	**Primary Productivity** (Tiles)		**Primary Productivity** (Rocks)			**Turbidity**		**Nutrient Diffusing Substrate Experiment**		**Water Chemistry**				**Dissolved Oxygen Concentration**		**Periphyton & Invertebrate Isotope**		**Fish Isotope** (Chinook and Steelhead only)			**Secondary Productivity - Invertebrates** (Hess & Drift)			**EMAP Habitat surveys**
	Aug	Sep	Jul	Aug	Sep	Jun	Aug	Aug	Sep	Jun	Jul	Aug	Sep	Jul	Sep	Jul	Sep	Jul	Aug	Sep	Jul	Aug	Sep	Aug
Bear Valley Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X
Camas Creek	X	X	X	X	X		X				X	X	X	X	X	X	X		X	X	X		X	X
Cape Horn Creek			X	X	X	X	X			X	X	X	X	X	X	X	X	X		X	X		X	X
Chamberlain Creek	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X		X	X	X		X	X
Elk Creek	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X	X		X	X		X	X
Elk Tributary to Valley Creek			X	X	X	X	X			X	X	X	X	X	X	X	X			X	X		X	X
Lake Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X
Loon Creek	X	X	X	X	X		X	X	X		X	X	X	X	X	X	X		X	X	X		X	X
Lower Big Creek	X	X	X	X	X	X	X			X	X	X	X	X	X	X	X		X	X	X		X	
Marsh Creek			X	X	X	X	X			X	X	X	X	X	X	X	X	X		X	X		X	X
Rush Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X
Secesh River	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	
South Fork Salmon River	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X
Sulphur Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X		X	X
Summit Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X
Valley Creek			X	X	X	X	X			X	X	X	X	X	X	X	X		X	X	X		X	X
West Fork Chamberlain Creek	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X		X	X	X		X	X
South Fork Salmon Enclosures	X	X								X		X	X					X	X	X	X	X	X	

Table 3. Summary of water chemistry and periphyton data from 17 streams sampled in summer 2002 and 2003. Included are the mean, minimum, maximum, and standard deviation of values observed across all streams. Nutrients, total phosphorus (TP) and total nitrogen are in concentration units (µg/L). Ash-free dry mass (AFDM) and chlorophyll (CHL) are calculated on an aerial basis (mg/cm^2, and ug/cm^2).

		Mean	Minimum	Maximum	Standard Deviation
PO_4	2002	3.61	0.29	16.24	3.37
	2003	4.35	0.37	19.71	3.88
SiO_4	2002	5955.45	3967.33	8993.05	1289.60
	2003	5601.08	1041.04	9241.55	1452.80
NO_3	2002	3.22	0.00	24.29	6.54
	2003	5.33	-0.04	72.51	11.13
NO_2	2002	0.13	0.00	0.34	0.09
	2003	0.17	-0.07	0.75	0.12
NH_4	2002	3.34	1.19	6.25	1.17
	2003	2.76	0.39	9.73	1.68
TP	2002	28.93	17.44	49.37	7.40
	2003	24.80	13.13	80.95	8.34
TN	2002	166.69	99.35	280.82	37.25
	2003	110.29	45.68	751.83	64.56
AFDM	2002	0.30	0.08	0.56	0.13
	2003	0.30	0.00	6.16	0.52
CHL	2002	25.71	1.12	151.34	32.85
	2003	1.11	0.01	115.51	7.13

Table 4. Timing and nature of research activities for the Salmon River nutrient enhancement study.

	2002	2003	2004 & beyond…
Baseline Monitoring	X	X	X
Stream enclosure experiments in ID		X	
Stream channel experiments in WA			X
Ecosystem nutrient enrichment experiment in ID			X

Table 5. Proposed ecosystem nutrient addition experiment for summer 2004. Listed stream choices are pending permit approval from United States Forest Service. Treatments will be added in the lower 1-km reach in each stream between late July and mid-August.

Treatment	Number of Streams
Analog (Bear Valley and Sulphur)	2
Carcass (South Fork Salmon and Summit)	2
Inorganic Nutrients (Elk and Lake)	2
Control (Valley and Marsh)	2
TOTAL	**8**

Table 6. Variables monitored during baseline data collection in the summer of 2003 and additional variables that will be monitored during summer 2004.

Data Category	Variables Measured in 2003	Additional Variables for 2004
Physical Characterization	Channel Width Gradient Channel characteristics -habitat type -sinuosity -substrate composition -water depth Riparian Vegetation Pebble counts Temperature -maximum daily -minimum daily -mean daily Flow Rate	Channel Width* Gradient* Channel characteristics* -habitat type* -sinuosity* -substrate composition* -water depth* Riparian Vegetation* Pebble counts* Temperature -maximum daily -minimum daily -mean daily Flow Rate
Water Chemistry	Total - Nitrogen - Phosphorus Nutrients - PO_4, $Si(OH)_4$, NO_3, NO_2, NH_3 Dissolved Organic Carbon Turbidity	Total - Nitrogen - Phosphorus Nutrients - PO_4, $Si(OH)_4$, NO_3, NO_2, NH_3 Dissolved Organic Carbon Turbidity
Primary Productivity	Periphyton Biomass (rocks and tiles) - ash free dry mass - chlorophyll concentration Isotope Composition	Periphyton Biomass (rocks and tiles) - ash free dry mass - chlorophyll concentration Isotope Composition
Invertebrate Community	Community biomass and density Species composition Isotope composition	Community biomass and density Species composition Isotope composition
Decomposition	Leaf litter decomposition rate	None
Fish Community	Individual survival (Achord Study) Species composition Abundance/Density/Biomass Size structure Isotope Composition Behavioral interactions among chinook and brook trout in Summit Creek	Individual survival (Achord Study) Species composition Abundance/Density/Biomass Size structure Isotope Composition Behavioral interactions among chinook, brook trout, and other resident trout in treatment streams
Bird Community	Species composition and abundance Behavior	Species composition and abundance Behavior
Nutrient Limitation Study	Chlorophyll accrual of in-stream nutrient diffusing substrates	Chlorophyll accrual of in-stream nutrient diffusing substrates
*Only for streams lacking 2 habitat surveys from 2002 -2003		

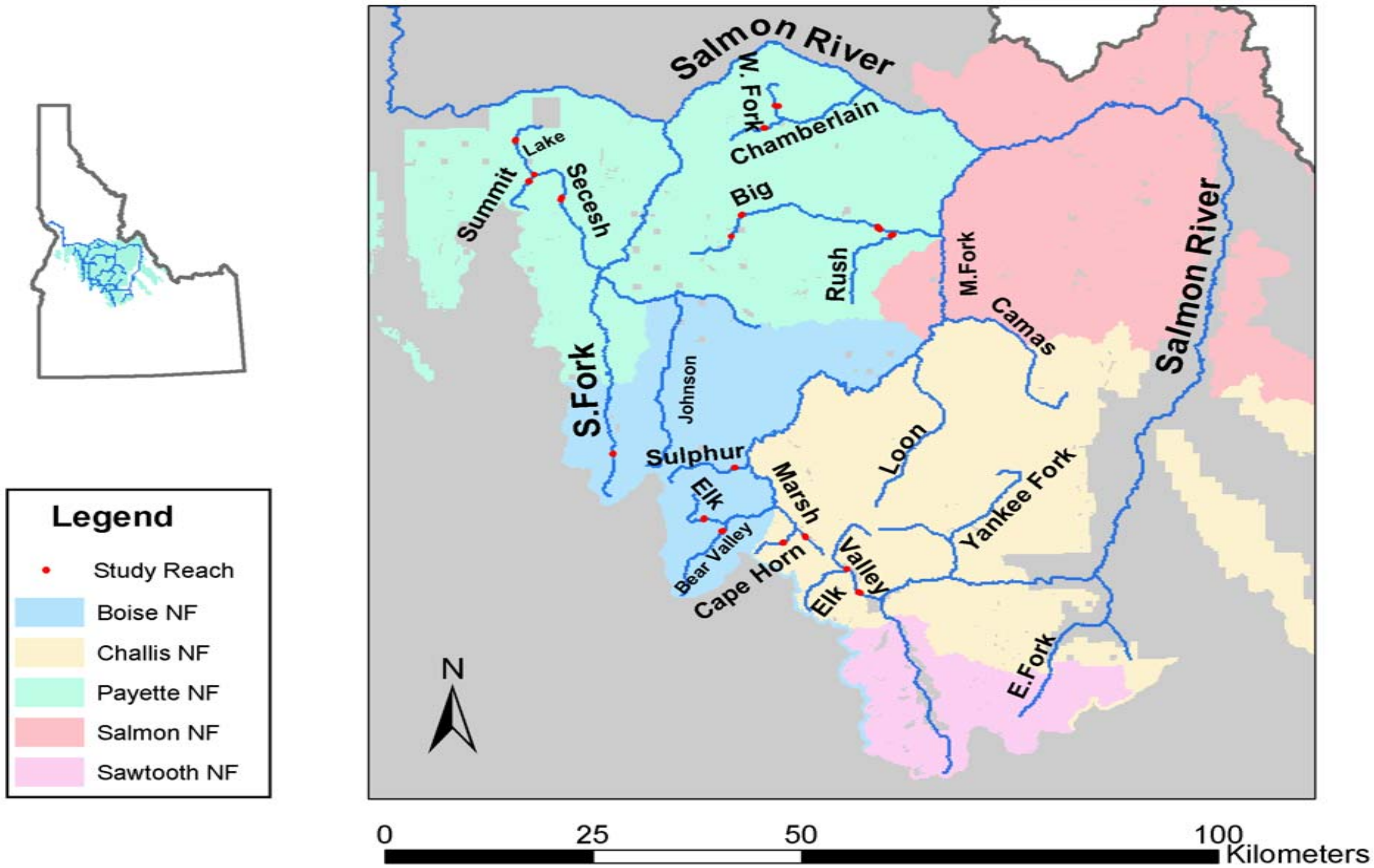

Figure 1. Map of study streams in the Salmon River Basin. Dots on individual streams identify the location of sampling reaches. Shading depicts the five different National Forests.

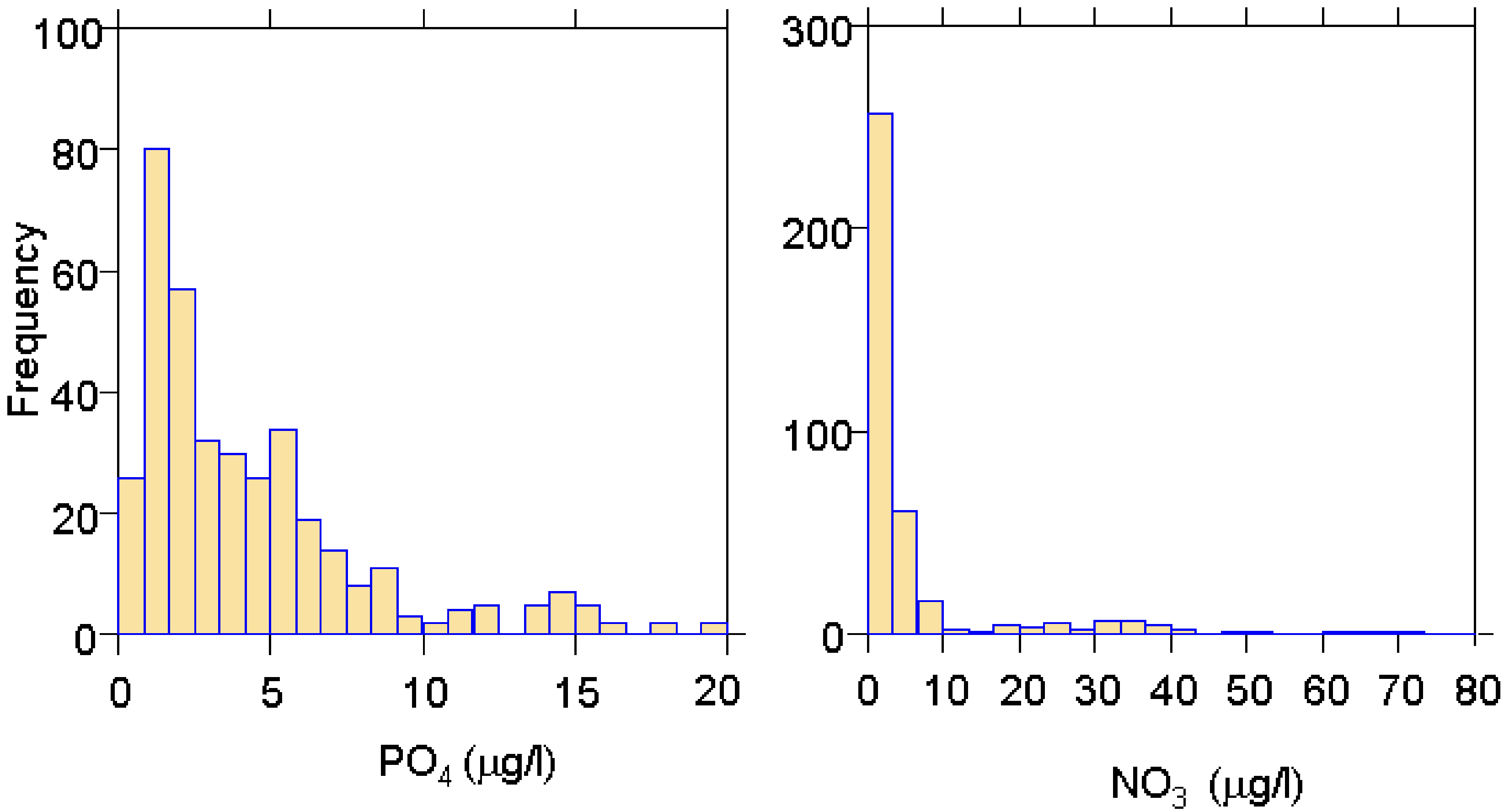

Figure 2. Histograms of phosphate (PO_4) and nitrate (NO_3) concentrations measured in the 17 streams sampled in 2003. Observations include 3-6 sampling points between June-September in each stream. Note low nitrate concentrations across sampled streams.

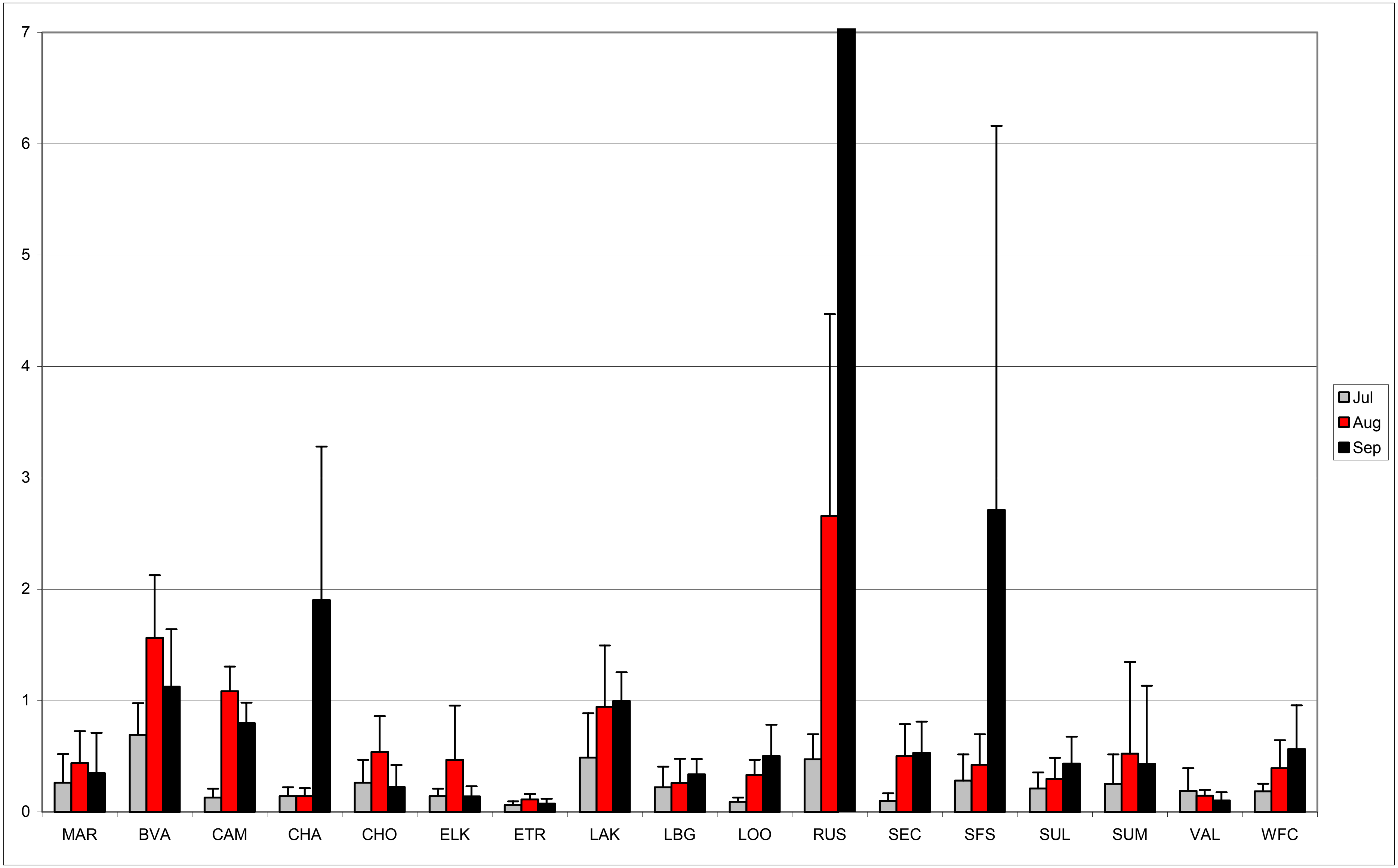

Figure 3. Chlorophyll concentrations (ug/m^2) of periphyton collected from rocks in the 17 streams sampled in late July, August, and September 2003. Chlorophyll concentration for Rush Creek in September measures 55.6 ug/m^2.

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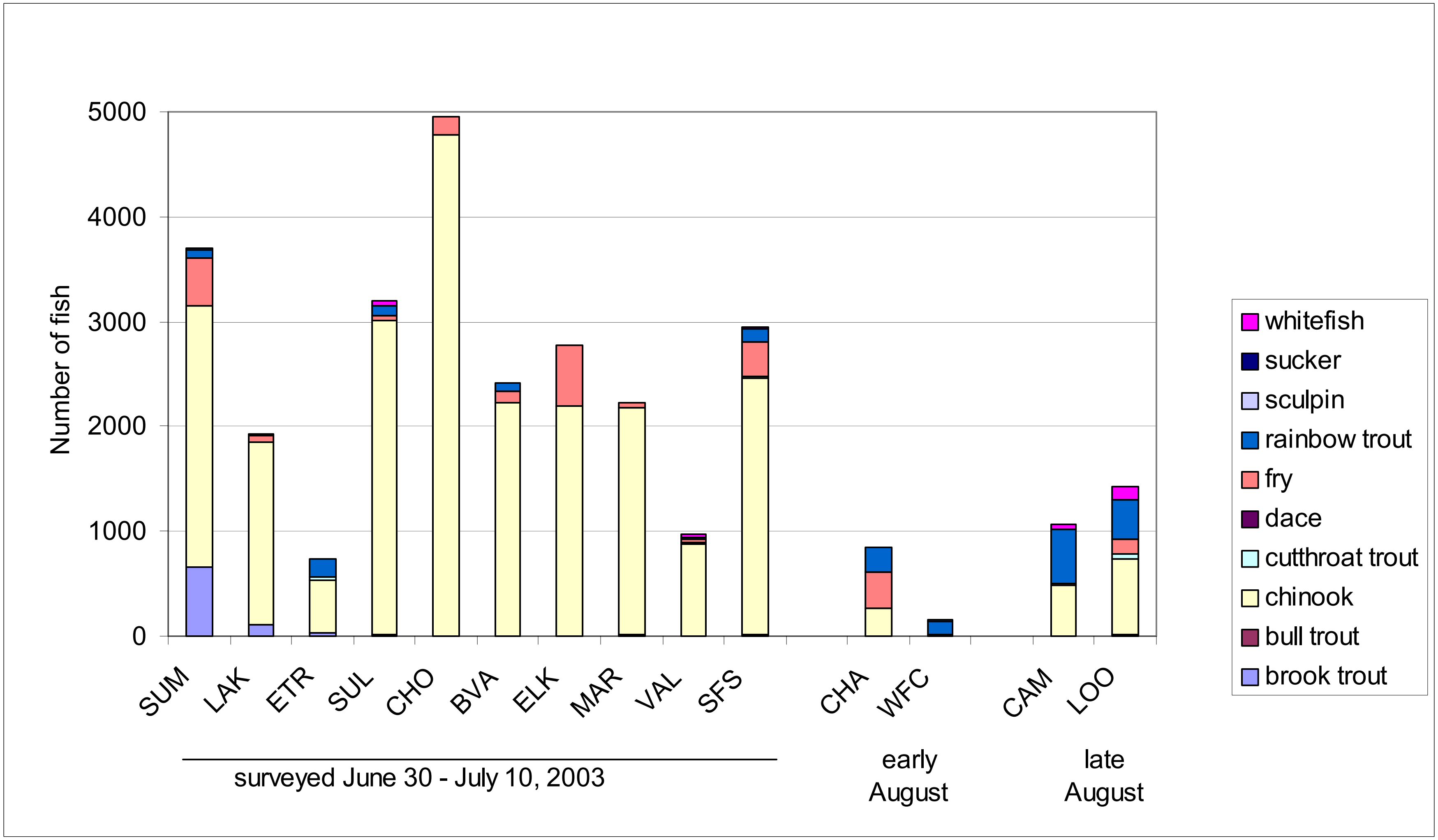

Figure 4. Fish abundance by stream and species (all chinook observed <40 mm considered unidentified fry) as surveyed in two 200-m reaches in each stream. Snorkel surveys completed by multiple divers between late June and late August 2003.

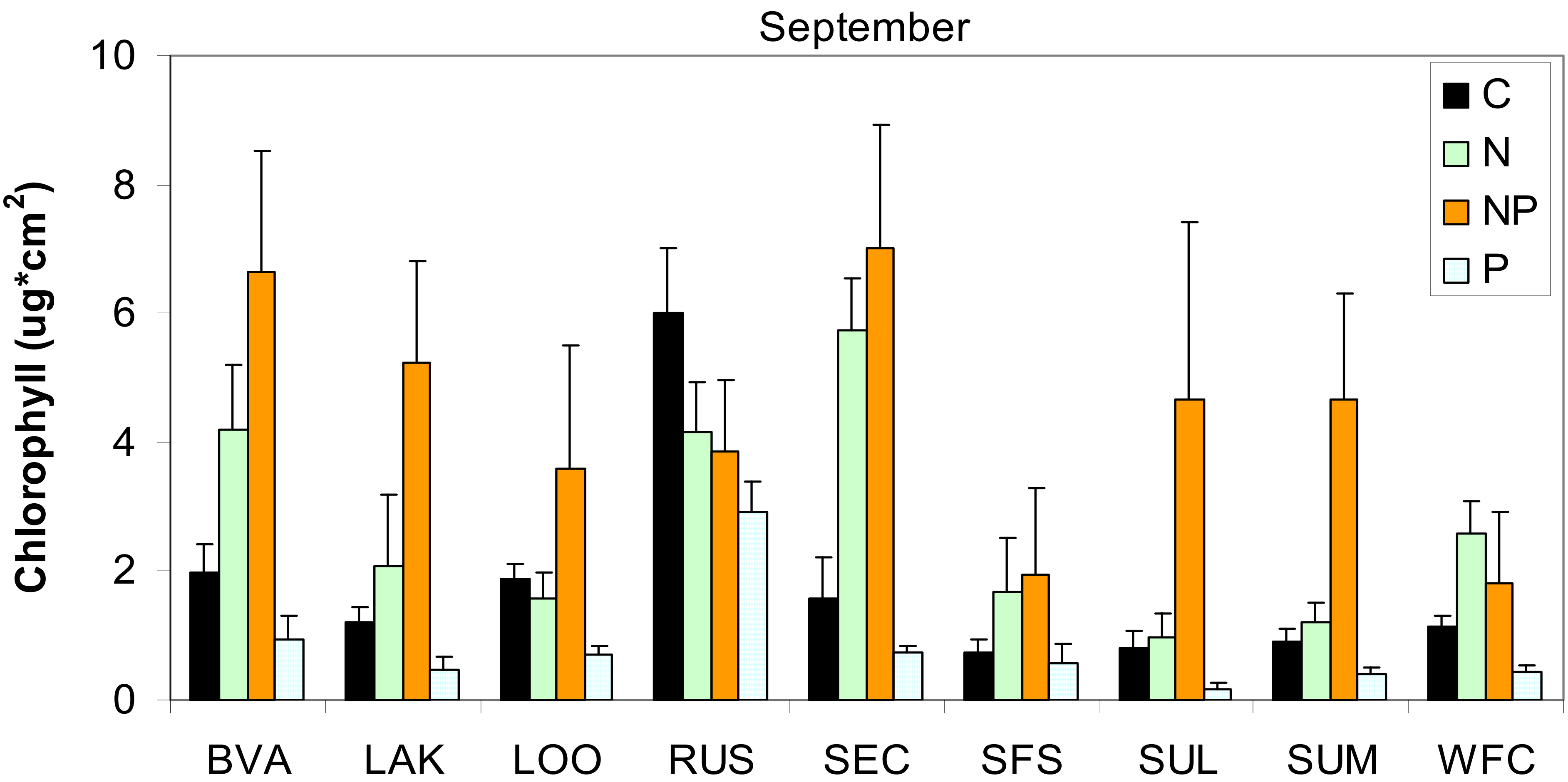

Figure 5. Chlorophyll a concentrations (ug/cm^2) measured from nutrient diffusing substrates placed in nine streams for one month between August and September 2003. Chlorophyll a concentrations in all streams except Rush and Loon are limited by nitrogen ($p<0.05$), and all streams except Rush, South Fork Salmon, and West Fork Chamberlain are co-limited by nitrogen and phosphorus treatments ($p<0.05$).

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